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Drivers behind farm-level adaptation in Africa: a composite index of potential adoption

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Abstract

In the last decades there has been a growing concern about the drivers behind adoption of adaptation strategies at the farm-household level. This paper aims to synthesise this past research in order to scale up farm-level adoption through a composite index of potential adoption in Africa. In doing so, we review the estimated coefficients of econometric regressions in 42 case studies published in peer-review journals in order to identify the factors that regularly explain adoption. We find that these common factors can be grouped into seven components, that is human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture, and attitudes towards the environment. Using national-level indicators of these seven categories we develop a composite index to inform potential adoption and the robustness of the index is tested in an in-depth sensitivity analysis. The results show that the highest likelihood of adoption of farm-level adaptation strategies is in Northern African countries namely Tunisia, Egypt, Algeria and Morocco, and in Southern African countries such as South Africa and Botswana. Conversely, they indicate that the lowest likelihood of adoption is situated in nations of the Sahel and Horn of Africa and in nations that have recently experienced conflict. We conclude that adoption is associated predominantly with governance, civil rights, financial resources, and education and is not necessarily associated with climate change impacts on agricultural production.

Keywords: Adaptation strategies, Adoption, Africa, Climate change, Composite Index, Farm-level

1. Introduction

The sustainable development of agriculture in Africa as well as its contribution to food security and economic growth is threatened by climate change (Parry et al. 2004; Lobell et al. 2008; Ngigi 2009). The Fifth Assessment Report of the IPCC (AR5) (Niang and Ruppel 2014) foresees with a high level of confidence that climate change along with non-climate drivers will exacerbate vulnerability of agricultural systems due to an increase in temperature and changes in precipitation patterns. Rural communities are especially vulnerable due to an elevated dependence on agriculture and a limited resilience to cope with novel situations (Schmidhuber and Tubiello 2007). Consequently, smallholder farmers have no alternative but to adapt their livelihood systems to changing climatic conditions (Ngigi 2009).

IPCC AR5 highlights the importance of farm-level adaptation strategies in order to reduce climate change vulnerability and to make farm-households better able to adjust to the changing climate avoiding or diminishing potential damages (Niang and Ruppel 2014). According to the classification of the Fifth Assessment (IPCC 2014), farm-level adaptation strategies include the category of technological (e.g. changing crop and livestock varieties, water management innovations, conservation agriculture, early warning systems), ecosystem-based category (e.g. afforestation and reforestation), educational (e.g. extension services, communication through media), and behavioural (e.g. soil and water conservation, changing cropping practices, patterns and plant dates, reliance on social networks).

IPCC AR5 also points out the potential that public and private institutions have to enhance adoption of farm-level adaptation strategies. In this context, in all regions of the continent national governments are initiating governance systems and developing numerous policies and programmes (Niang and Ruppel 2014). These frequently aim at integrating adaptation to climate change into policies related to sustainable development, food security and poverty (AAP 2013; Beddington et al. 2012; IFAD 2013) and usually target those people most vulnerable to climate change (Nzuma et al. 2010; Downing et al. 1997). An example of this is the Africa Adaptation Programme (AAP) (2013) by the United Nations Development Programme (UNDP) which has recently implemented a programme with the purpose of enhancing adaptive capacity, promoting early adaptation action and laying foundations for long-term investment in order to increase resilience of farm-households to climate change.

These policies are often developed at elevated scales such as the whole African continent, and are based on the information provided by case studies conducted at the local level (UNFCCC 2011). However, since policies are frequently based on a small number of case studies their effectiveness may be rather low due to the high heterogeneity of factors affecting adoption of adaptation strategies. In this context, the AR5 highlights with high confidence the need for enhancing and scaling up adaptation responses at the local level including principles for good practice and integrated approaches to adaptation (Niang and Ruppel 2014). Therefore, assessing farm-level adoption through an approach which covers the whole African continent can provide helpful information to develop policies to enhance adaptive capacity for coping with a variety of risks associated with climate change (Nhemachena and Hassan 2007). This study develops a composite index of the uptake of adaptation in African based on numerous

local-level case studies. Thus the composite index provides an understanding of the probability of farm-level adoption in the different regions, and helpful information to design policies and programmes at regional scales. Nevertheless, the accuracy of estimates when scaling up adoption can be limited by the variability in climate change impacts across the continent and natural limits to adaptation such as soil quality. This limitation points out the need for a large number of local-level case studies in order to identify reliable patterns across the case studies.

In order to provide a better understanding of how farm-level adoption can be improved through policy intervention there has been a growing interest around the drivers of uptake of adaptation strategies. In this context, particular attention has recently been placed upon analysing the effect of socio-demographics and farm characteristics on adoption of farm-level adaptation measures (e.g. Gbetibouo 2009; Deressa et al. 2009; Bryan et al. 2009; Silvestri et al. 2012). These determinants can act as biophysical, economic or social motivations or barriers to the potential uptake of recommended agricultural practices at the farm level against climate change. Since smallholders represent the most vulnerable stakeholders and implementation of adaptation will ultimately proceed on a local or individual scale understanding adoption of farm-level adaptation strategies seems to be an appropriate first step for a bottom-up approach as well as to identify the drivers behind the adoption of adaptation.

Previous reviews of farm level adoption of recommended agricultural practices have been conducted to explore those factors that regularly explain or influence adoption (e.g. Baumgart-Getz et al. 2012; Knowler and Bradshaw 2007). Typically these studies analyse the estimated coefficients of the independent variables of econometric regressions conducted in previous studies. These studies usually attempt to establish common baselines to inform policies that can enhance adoption of recommendable agricultural practices considering the results of numerous studies. However, these reviews often do not attempt to map these common baselines in order to identify regions which are more or less likely to adopt certain agricultural practices. Whilst numerous studies have assessed and regionalised adaptive capacity and vulnerability to climate change in Africa (e.g. Naumann et al. 2014; Thornton et al. 2006; Brooks et al. 2005) there is clearly a gap in the literature on studies attempting to estimate spatially explicit adoption of farm-level adaptation strategies with the African farming context. Accordingly, this work aims to bridge this gap between the large body of literature on adoption of farm-level adaptation strategies and studies that regionalise adaptive capacity and vulnerability to climate change.

The aim of this paper is to provide a regionally explicit composite index that explains the likelihood of adoption of farm-level adaptation strategies. Thus it provides an upscaled assessment of potential adoption for the whole African continent. Accordingly, the paper is structured as follows. The next section outlines the data collected, namely the review of case studies and the methodology used to identify both the factors that regularly explain adoption and approaches towards aggregating them into components. Then, the composite index is presented and discussed, and the sensitivity to aggregation and weighting is also explored to assess the robustness of the index. Finally the limitations, policy implication and findings of this work are discussed.

2. Data and methods

2.1 Framework

The methodological process aims to provide a transparent construction of a robust composite index that can be easily replicated in other regions. It can be described in the following six methodological steps:

- i. Selection of case studies in Africa that assess through econometric regressions adoption of farm-level adaptation strategies
- ii. Identifying independent variables in econometric regressions of past research that regularly explain adoption
- iii. Grouping these independent variables into components
- iv. Selecting indicators from public databases that define each component of the composite index
- v. Estimating the likelihood of adoption of farm-level adaptation strategies through the calculation of the API in Africa.
- vi. Analysing limitations of the composite index and sources of uncertainty by a sensitivity analysis

2.2 Selection of independent variables that regularly explain adoption and relevance

The selection of indicators of a composite index should be based on the analytical soundness, measurability, and relevance to the phenomenon being measured and their relationship to these phenomena (OECD 2008). In this study, the selection of indicators was based on the review and synthesis of 100 econometric regressions conducted in 42 case studies. All case studies were conducted in Africa, published in peer-review journals, and presented the common objective of assessing by econometric regressions the influence of socio-economic factors on the uptake of farm-level adaption strategies. Thereby we analysed the estimated coefficients of the econometric regressions presented in the studies in order to identify those independent variables that regularly explain adoption in Africa, and thereby could be used to estimate a composite index about potential adoption.

The table in Appendix A presents these case studies and describes their sample size, approach, and evaluated adaptation strategies through econometric regressions. The case studies covered the African continent and the majority of them used a logit or probit econometric approach. Following the typology of adaptation strategies defined by Smit and Skinner (2002) the strategies of the case studies broadly could be classified into two major groups. The first group deals with adoption of technological developments which includes adaptation strategies such as crop development of new crop varieties (17% of econometric regressions), technological innovations (6%), and agrochemicals (11%). The second group is adoption of farm production practices and includes adaptation strategies such as changes in farm production (16%), land use (7%), land topography (10%), irrigation and water conservation (12%), timing of operations (7%), organic fertilizers (5%), and others (9%).

The next step was to group into components the selected independent variables that regularly explain adoption of adaptation strategies. The fact that all case studies were conducted at the farm level and in the same region made the identification of components more consistent and reliable.

Through publically available databases (REFERENCES HERE) , national-level indicators of the identified components were used to calculate the composite index. The selection of these national-level indicators was based on three criteria: (i) the indicator had to represent a quantitative or qualitative aspect of both adoption of adaptation and the identified components, (ii) data needed to be available in public databases, and (iii) each indicator had to have at least 50% of the countries without missing data (Naumann et al. 2014; OECD 2008). This emphasis on public databases ensures that the final result can be validated, reproduced and improved with new data (Vincent 2004; Naumann et al. 2014). Moreover, the divergence of the independent variables of the econometric regressions towards a positive and significant influence on adoption was also considered to select national-level indicators of the components.

For those countries that presented missing data the values were completed from secondary sources and from data from neighbouring countries with similar biophysical and socio-economic characteristics. Whilst the selection of substituted countries for biophysical characteristics was based on climate characteristics and on the proximity between countries for socio-economic characteristics, the selection was based on similar values of GDP per capita and cultural factors, such as..... It is important to highlight that this substitution of missing values can be an important source of uncertainty in the final output of the composite index. For this reason the effect of data substitution should be tested in the sensitivity analysis and the interpretation of the results should be discussed considering these sensitivities. Vincent (2004) recommends the substitution for missing values when it is unavoidable, given the indicator data availability, and points out the risk of basing these substitutions on subjectivity alone. He claims that the only solution is to make such choices transparent, in order to enable effective critical evaluation of the robustness of the index.

2.3 Calculating the Adoption Potential Index (API) of farm-level adaptation strategies

Once collated, the national-level indicators needed to be normalised to allow direct comparison between results among countries, as most indicators had different measurement units. Normalisation was calculated considering the minimum and maximum value of each indicator across all countries to guarantee that all indicators had an identical range between 0 and 1 following the same methodology as in Naumann et al. (2014). Similar methodologies have been widely used for calculating composite indexes (e.g. Brooks et al. 2005; OECD 2008; Thornton et al. 2006; Vincent 2004). For indicators with a positive correlation to the overall potential adoption index, the normalized value (NI_i) was calculated according to the following linear transformation:

$$NI_i = \frac{I_i - I_{min}}{I_{max} - I_{min}} \quad (1)$$

where I_i is the indicator value for a generic country i , I_{min} and I_{max} the minimum and maximum value across all countries i . For indicators with a negative and statistically significant correlation with the overall composite index, the normalised values of the index were reversed. In this way, all normalized indicators (NI_i) had values ranging between 0 (lowest potential adoption of farm-level adaptation strategies) and 1 (highest potential adoption).

For each country, any of the j ($j = 1, \dots, 7$) components (C) were calculated as the mean of the normalised indicators NI_i that define each component (Equation 2). Finally, Equation 3 shows how the overall API of each country was calculated as a weighted aggregation of the components.

$$C_j = \frac{1}{n} \sum_{i=1}^n NI_{ij} \quad (2)$$

$$API_i = \sum_{j=1}^7 W_j C_{i,j} \quad (3)$$

Where W_j are the weights assigned for the j component (with $\sum w_j = 1$) and $C_{i,j}$ are the components for each country. Thus the scores of the API are the relative index value of a country with respect to the remainder of the countries. These values range from 0 to 1, where 0 represents the lowest likelihood of adoption of farm-level adaptation strategies and 1 is associated with the highest likelihood.

As no perfect weighting and aggregation convention exists for developing composite indexes (Arrow 1963) it was necessary to test the robustness and stability of the weights. Following the study by Naumann et al. (2014), we used three different weighting schemes to test the influence of weighting on the API: equal weights among components (equal weights), weighting scheme according to the number of indicators in each component (proportional weights), and random weights (using the Monte Carlo method with 1000 simulations).

2.4 Sensitivity and sources of uncertainty

Sensitivity analysis is normally used to assess the robustness and validity of composite indicators (OECD 2008). It focuses on how uncertainty in the input factors (i.e. indicators, weighting, and aggregation) propagates through the overall structure of the index. Typically the sources of uncertainty are derived from the subjective judgements of the researcher for constructing the index (OECD 2008). In this study, the main sources of uncertainty were derived from two subjective judgements: (i) the selection of the aggregation and weighting methods, and (ii) the substitution of country data for countries that presented missing values. In order to analyse the uncertainty of these two sources, different Monte Carlo experiments were computed to assess the contribution of any individual source of uncertainty to the output variance. This methodology is based on multiple evaluations of the model with different weighting and aggregation schemes that generate different probabilistic density functions of model outputs (Naumann et al. 2014). Furthermore, the robustness of the index was also analysed by the stability of the country rankings assigned by the index value in the sensitivity

analysis. Thereby, the shift in country rankings reflected the uncertainty associated to each input factor.

The sensitivity to the weighting scheme and aggregation of components was tested by analysing the effect on the composite index of all countries when assigning random weights to the components. In doing so, 1,000 repetitions were done for the values of the components weights in order to compute the API. The other source of uncertainty, i.e. substitution of missing data, assessed the effect on the final output of the API by assigning random values for indicators of those countries that presented missing data. Thereby for each weighting scheme 1,000 repetitions were computed assigning random values to those countries that presented missing data.

3. Results

3.1 Selection of independent variables that regularly explain adoption of adaptation strategies

The first step of the methodological process was to select case studies in Africa assessing adoption of farm-level adaptation strategies through econometric regression techniques. Subsequently, the estimated coefficients were used to identify those independent variables that are regularly used to explain adoption. Among the 100 analysed econometric regressions, 26 independent variables were selected (Table 1). Those independent variables that were infrequently used were excluded from the analysis as they were unlikely to provide much information or to show a pattern across empirical studies (Knowler and Bradshaw 2007). Table 1 describes detailed information about the components, sign and significance of each independent variable in the econometric regressions of the case studies. Whilst several statistical thresholds indicating significance were presented across the studies we selected 5% as the cut-off for our analysis.

The next step was to aggregate the independent variables into components regarding similarities. Thereby aggregation was undertaken into seven components in terms of human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture, and attitudes towards the environment.

Human capital is the component most frequently assessed across the case studies. Education, farming experience and household size are the independent variables that seem to show better convergence towards a positive and significant influence on the adoption of adaptation strategies. Despite farmer's age being an independent variable frequently assessed, our results show that its correlation with adoption of adaptation is very questionable, confirming the findings by Knowler and Bradshaw (2007). Approximately 58% of the econometric regressions found insignificant relationships between age and adoption (e.g. Asfaw and Admassie 2004; Di Falco et al. 2011). Among the significant relationships, 59% had a positive effect (e.g. Gebrehiwot and van der Veen 2013; Oben Tabi et al. 2012) and 41% a negative effect (e.g.

Somda et al. 2002; Marenya and Barrett 2007). In the case of gender, approximately 70% of the econometric regressions found a statistically insignificant relationship.

The independent variables within financial resources are regularly assessed but do not seem to reflect plain convergence towards a positive and significant influence on the adoption. Credit access, wealth indicators and livestock ownership are the variables that show the highest convergence. Farm size is the independent variable most frequently assessed of the component. Among the significant relationships, around 68% of the regressions found a positive effect and 32% a negative effect. Within the component of infrastructure and technology the variable of high availability of technology in the farm (i.e. 'technology') presents the highest convergence towards a positive and significant correlation.

The component of social interaction and governance presented the highest positive and significant correlation with adoption. The independent variables most frequently assessed within the component are access to extension services, climate information, and membership of organizations. All these independent variables are related to networking capacities and numerous studies have revealed both positive and significant influence on adoption (e.g. Bryan et al. 2009; Deressa et al. 2009; Abdulai et al. 2011).

The independent variable of off-farm activities represents the relative dependence on agriculture. Its relationship with adoption does not seem very clear as approximately 67% of the regressions have a positive and significant relationship and in 33% of the cases, were negative and significant. The components of food security and attitudes towards the environment and climate change are the least frequently assessed. In the case of food security, only seven regressions out of fourteen found a significant relationship. Finally, all independent variables within the attitude component seem to reflect a slight positive and significant relationship with adoption (e.g. Sidibé 2005; Okoye 1998; Shiferaw and Holden 1998; García de Jalón et al. 2013).

< INSERT TABLE 1 HERE >

3.2 Selection of national-level indicators

The selection of indicators from national-level public databases was carried out on the basis of the previous identification of components through the synthesis of econometric regressions of past research. All African countries were included in the analysis with the exemption of Comoros, São Tomé and Príncipe, Seychelles, and Western Sahara because of insufficient available data. In total, 28 national-level indicators from public databases were selected and aggregated in the seven components previously identified through the synthesis of past research.

Table 2 summarizes the selected national-level indicators and the source of the databases. Human capital basically includes indicators of education and density of population. Among the

analysed econometric regressions, the independent variables of this component that show the highest convergence towards a positive and significant relationship with adoption were education, farming experience and household size. Whilst the national level indicators of literacy rate, school enrolment and progression of females to secondary school seem to be adequate in indicating education, density of population reasonably matches with household size.

The selected indicators of financial resources were GDP per capita, ease of doing business and economically active females. Within the component of infrastructure and technology, the indicators of isolation of rural communities match relatively well with distance to market, irrigation infrastructure and sanitation facilities with infrastructure, and scientific and technical articles with technology.

Comment [A1]: What do you mean by articles?

The component of social interaction and governance include public institutions, agricultural networks and interactions between farmers and public institutions. Thereby, the indicators of this component were related to dissemination of information, such as mobile cellular and internet users and to governance and regulatory frameworks, such as political stability, governance effectiveness and regulatory quality.

The indicators used for food security were population undernourished and malnutrition prevalence among children. The indicators of dependence of agriculture were agricultural population, area, % of GDP and potential cereal yield. The component of attitudes towards the environment was represented by indicators of environmental stress such as percentage of freshwater withdrawal and forest area and by the percentage of organic area of cultivated area.

The indicators 'ease of doing business' index, 'population undernourished', 'malnutrition prevalence between children', 'agricultural population', and 'value added of agriculture to GDP' were reversed because they had a negative and statistically significant correlation with the adaptation adoption index.

< INSERT TABLE 2 HERE >

3.3 Estimating regional potential adoption of farm-level adaptation strategies

In order to understand the derivation of the API it is useful to analyse the value of the components separately (Naumann et al. 2014). Fig. 1 shows the value of the components for each of the 49 African countries.

Tunisia, Egypt, South Africa, Morocco, and Algeria present the highest values of the composite index. All of them have values close to or higher than 4. They have the highest value of human capital, infrastructure, food security and attitudes towards the environment. On the contrary, the five countries with the lowest values are Chad, Eritrea, Niger, Democratic Republic of Congo and Somalia with API values close to 0.2. These countries present the lowest value of

Comment [A2]: Please explain why 4? – you mention normalised 0 to 1 so unsure where the 4 comes from??

financial resources, social interaction and governance, food security and dependence on agriculture.

< INSERT FIGURE 1 HERE >

Fig. 2 presents the map by deciles of the API. According to the geographical divisions of the African Union, Northern Africa indicates the highest likelihood of adoption of farm-level adaptation strategies followed by Southern Africa, Western Africa, Central Africa, and lastly Eastern Africa. It is noteworthy to highlight that our results emphasise the fact that climate change impacts on agriculture and likelihood of adoption of adaptation seem not to be strongly correlated. Accordingly, whilst climate change projections seem to indicate that the Sahelian Belt and some parts in Northern and Southern Africa will suffer the largest impacts on agricultural yields (Fischer et al. 2005; Schlenker and Lobell 2010; Thornton et al. 2006; Niang and Ruppel 2014; Parry et al. 2004) our index shows that the Sahelian Belt has the lowest probability of adoption and Northern and Southern Africa the highest probability.

< INSERT FIGURE 2 HERE >

3.4 Sensitivity analysis of the composite index

Sensitivity analysis was used to evaluate the robustness and validity of the results by estimating the degree of uncertainty associated with the construction of the API. It also helped to identify which countries were favoured or weakened under the different assumptions of the index.

Fig. 3 shows the sensitivity of weights and components in the API values and country ranks. Broadly, API values and country ranks in the sensitivity to weights were less dispersed than in the sensitivity to components. This points out that the API was less sensitive to the value of weights than to the value of components.

Within the sensitivity to components, the weighting schemes of equal and proportional weights were notably more robust than the random weights scheme. These results suggest that the schemes of equal and proportional weights were more robust with respect to missing data. According to the output variance, the equal weights scheme was the most robust scheme followed by proportional weights and random weights.

Overall, Fig. 3 demonstrates that our results are moderately robust since considering only the values inside the boxes, i.e. fifty percent of the estimations, the ranking of the index among countries did not significantly vary except in the random weights scheme.

< INSERT FIGURE 3 HERE >

4. Limitations, implications and conclusions

This study presents an innovative approach to evaluating smallholders' adoption of farm-level adaptation for the whole African continent. However, there are number of limitations which need to be addressed.

Firstly, the selection of indicators is based on a synthesis of independent variables in numerous econometric regressions to evaluate different types of adaptation strategies. Thereby all adaptation strategies were treated as if they were driven by the same independent variables. This limitation would have been avoided with a greater sample of case studies which would have allowed classifying adaptation strategies into more homogenous groups. This would lead to a higher accuracy of the composite index since different independent variables would have been used for different adaptation strategies. However, the number of case studies that are conducted in Africa and published in peer review journals is not large enough to enable this categorisation in terms of types of adaptation strategies and sub-regions of Africa. Consequently, extending this approach would require detailed scrutiny of non-published, or grey literature on adoption which these authors did not have access to. Secondly, evaluating farm-level adoption entails an individual's behaviour in terms of the decision-making process. This complicates the generalisation of adoption at higher scales due to the irrationality of human behaviour (Kiome and Stocking 1995). Moreover, other factors such as cultural and behavioural barriers can play a crucial role in the adoption of adaptation (Nielsen and Reenberg 2010), but their inclusion in a national-level analysis seems to be very ambitious. In order to include a component of national-level attitudes we selected indicators that reflect societal attitudes towards the environment, such as percentage of organic agriculture, forest area and freshwater withdrawal. Thirdly, our composite index was calculated as a weighted average of the identified components which assumes strong relationships among the indicators. Nevertheless, as there is no consensus on the selection of weights in composite indexes (OECD 2008) our index was computed by three different weighting schemes. Fourthly, the composite index only includes indicators related to socio-economic factors and does not include indicators related to natural factors such as climate and soil characteristics or climate change impacts on agricultural production. This is due to the influence on adoption of adaptation strategies of climate change impacts and natural factors, which is highly questionable and difficult to interpret or to establish general patterns. Whilst it could be argued that better natural conditions would lead to higher adoption rates due to higher yields and resources to adapt, it may be that worse natural conditions would lead to higher adaptation needs and consequently to higher adoption rates. The final limitation was the unavailability of completed data in datasets. Despite one of our requirements to select indicators to have at least 50% of the countries without missing data, and the total amount of missing data was not excessively high, the data of most of the selected indicators presented at least one country with a missing value.

Notwithstanding these limitations, the regional estimation of farm-level adoption of adaptation is an issue of international interest and can help policy makers to identify those regions where smallholder farmers are less likely to adapt to climate change and, consequently, to suffer more impacts.

The results of the API show that whilst Northern and Southern Africa have the highest likelihood of adoption of farm-level adaptation strategies, Central, Eastern and Western Africa have the lowest probability. It is worthwhile to note that the five countries with the highest probability of adoption, i.e. Tunisia, Egypt, South Africa, Morocco, and Algeria, border the Mediterranean Sea or have a Mediterranean climate. Conversely, the five countries with the lowest values are Chad, Eritrea, Niger, Democratic Republic of Congo and Somalia. With the exception of Democratic Republic of Congo, all of them share a Sahelian climate in which in the last decades, agriculture has suffered dramatic impacts from desertification and soil loss (Charney 1975; Giannini et al. 2008). Thus, our results emphasise that larger climate change impacts do not necessarily lead to higher probability of adoption, and there are other considerably more important drivers or limits to adoption such as lack of resources or low adaptive capacity.

Our results point out that war and conflict exacerbates a low rate of adoption of farm-level adaptation strategies. For instance, Democratic Republic of Congo and Somalia present the lowest API values and both countries have experienced numerous conflicts in the last decades. These results are in line with numerous studies that claim that conflicts aggravate a lower adaptive capacity and consequently a higher vulnerability to climate change (Brooks et al. 2005; Barnett and Adger 2007; Salehyan 2008).

The composite index developed in this study for assessing farm-level adoption of adaptation share many things in common with climate change vulnerability studies conducted in Africa (e.g. Thornton et al. 2006; Naumann et al. 2014; Brooks et al. 2005). Farm-level adoption is strongly influenced by the adaptive capacity of the farm, and together with the exposure to climate impacts determines the vulnerability to climate change (Smit and Wandel 2006). In line with our results, previous studies found that overall most vulnerable African countries are located in the Sahel (Thornton et al. 2006; Naumann et al. 2014; Brooks et al. 2005). In this way, our results seem to indicate that farm-households of Sahelian countries such as Burkina Faso, Chad, Eritrea, Ethiopia, Niger, Somalia and Sudan are less likely to adopt adaptation strategies despite the adverse impacts of climate change that they are currently suffering and are expected to be aggravated in the coming decades (Schlenker and Lobell 2010).

The approach provides a transparent procedure for the estimation of a composite index in order to assess farm-level adoption of adaptation, and offers a robust methodology for the identification of regions where smallholder farmers are less likely to adopt adaptation strategies. Thus the composite index suggests where there is more potential for improving adoption of adaptation strategies in Africa. The sensitivity analysis conducted to test the weighting schemes and component values show that our composite index is moderately robust and seems to be particularly appropriate to estimating regional adoption of farm-level adaptation strategies to climate change. Finally, as adaptation policies planned on global scales will ultimately be implemented on a local and regional basis, the results of this research can be

an approach to developing bottom-up approaches for the benefit of smallholder farmers to climate change.

Appendix A

< INSERT TABLE OF APPENDIX HERE >

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